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Indian Standard

TEST PROCEDURE FOR MEASUREMENT OF LOSS TANGENT ANGLE OF COILS AND BARS FOR MACHINE WINDING — GUIDE

UDC 621·313·048·2 : 621·3·017·143 : 621·317·333·6

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NEW DELHI 110002

September 1992 **Price Group 3**

Electrical Insulation Systems Sectional Committee, ETD 4

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Electrical Insulation Systems Sectional Committee had been approved by the Electrotechnical Division Council.

In large capacity rotating electrical machinery it is economical to operate at higher voltage. The insulation system of machines requires careful selection of materials leading to lower dielectric losses. The modern insulation systems include polymers which crosslink during the curing process.

The quality and condition of an insulation system can be evaluated in terms of dielectric strength, insulation resistance, dielectric loss, partial discharge, etc.

The uniformity of manufacture is judged to some extent by measurement of dielectric loss tangent as a function of voltage and by statistical evaluation of the test results.

For a known insulation system, it is possible to assess the following properties:

a) A low tangent at lower voltage ($0{\cdot}2\ U_N$) indicates a higher degree of molecular cross linking of bonding medium (degree of resin cure), and

b) The increment in tangent with increase in voltage gives indication of the void content of the insulation.

In the preparation of this Standard, considerable assistance has been derived from IEC Publication 894 (1987) 'Guide for a test procedure for the measurement of loss tangent of coils and bars for machine windings' issued by the International Electrotechnical Commission (IEC).

AMENDMENT NO. 1 OCTOBER 1995
TO
IS 13508 : 1992 TEST PROCEDURE FOR MEASUREMENT OF LOSS TANGENT ANGLE OF COILS AND BARS FOR MACHINE WINDING — GUIDE

(*Cover page and page* 1, *Title*) — Substitute the following for the existing title:

'TESTS PROCEDURE FOR MEASUREMENT
AND REQUIREMENTS OF LOSS TANGENT ANGLE OF
COILS AND BARS FOR MACHINE
WINDING — GUIDE'

(*Page* 1, *clause* 3.6, *line* 2) — Delete the word 'which'.

(*Page* 2, *clause* 4.2, *line* 6) — Substitute '100×10^{-3}' *for* '$100 \times 10\frac{1}{3}$'.

(*Page* 2, *clause* 4.2, *line* 7) — Substitute the word 'Sine' *for* 'cosine'.

[*Page* 2, *clause* 5.1.2(b)] — Substitute 'Increment (tan delta 0·6 U_N – tan delta 0·2 U_N)' *for* 'Increment tan delta 0·6 U_N — tan delta 0·2 U_N'.

(*Page* 3, *clause* 5.2.2.1, *line* 3) — Add the word 'the' after 'for' and delete the word 'the' after 'shielding'.

(*Page* 4, *clause* 5.3) — Add the following clauses after clause 5.3.1:

"**5.4 Permissible Values of Loss Tangent**

5.4.1 Values likely to be achieved on systems commonly used are indicated in **5.4.2**.

5.4.2 The initial value of tan delta 0·2 U_N, the increment 0·5 × (tan delta 0·6 U_N – tan delta 0·2 U_N) and the increment delta tan delta per measuring step up to U_N shall not exceed the values in Table 1 for rated voltages up to 11 kV (*see also* Fig. 1). For rated voltages above 11 kV the values should be fixed by agreement between manufacturer and user.

5.4.3 If more than 5 percent of the samples show test results in the ranges between col 2 and 3 or between col 4 and 5 of Table 1, or in a different range of agreed values, the testing shall be continued with an equal number of further samples, if necessary up to the total number of bars or coil sides. If during these tests the values of Table 1, or the agreed values, are not exceeded, the test of insulation shall be regarded as satisfactory.

5.4.4 If an automatic measuring system is used, conformity to the standard shall be determined at the reference voltages defined in this standard.

Table 1 Highest Permissible Values of Loss Tangent
(Rated Voltage not Exceeding 11 kV)

(*Clauses* 5.4.2 *and* 5.4.3)

Tan Delta 0·2 U_N	$\frac{\text{Tan Delta } 0{\cdot}6\,U_N - \text{Tan Delta } 0{\cdot}2\,U_N}{2}$		Delta tan Delta per Step of 0·2 U_N	
(1)	(2)	(3)	(4)	(5)
All samples	95 percent samples	Remaining 5 percent samples	95 percent samples	Remaining 5 percent samples
30×10^{-3}	$2{\cdot}5 \times 10^{-3}$	3×10^{-3}	5×10^{-3}	6×10^{-3}

5.5 Sampling Plan

The recommended sampling plan for carrying out the test is given in Table 2.

Table 2 Number of Bars or Coil Sides to be Tested

(*Clause* 5.5)

No. of Poles	Rated Output	No. of Test Samples
All polarities	Less than 1 MVA or MW	5 percent of coil sides
All polarities	1 to 5 MVA or MW	10 percent of bars or coil sides with a minimum of 20
Two and four	50 MVA or MW or greater	All bars or coil sides
	Less than 50 MVA or MW but not less than 5 MVA or MW	At least 60 bars or 60 coil sides and in addition, 10 percent of all bars or coil sides
Six and more	5 MVA or MW or greater	

(ETD 4)

Printed at New India Printing Press, Khurja, India

Indian Standard

TEST PROCEDURE FOR MEASUREMENT OF LOSS TANGENT ANGLE OF COILS AND BARS FOR MACHINE WINDING — GUIDE

1 SCOPE

1.1 This Guide is applicable to a method of measuring dielectric loss properties of the insulation system of the slot portions of new coils or bars for rotating electrical machines having rated voltage U_N of 5 kV and above.

1.2 This Guide is applicable to form wound coils or bars in which the insulation is cured before the winding is inserted in the stator.

1.3 This Guide also recommends in Annex A the test procedure of loss tangent on post impregnated machines but the evaluation criteria in not covered in this Guide.

2 REFERENCES

2.1 The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
2071 (Part 2) : 1976	Methods of high voltage testing: Part 2 Test procedure (*first revision*)
2260 : 1973	Preconditioning and testing of solid electrical insulating materials (*first revision*)

3 TERMINOLOGY

3.0 For the purpose of this standard, the following definitions shall apply.

3.1 Loss Tangent (Tan δ)

The tangent of the dielectric loss angle of an insulation system as a function of voltage.

NOTE — Other terms sometimes used for this property are tan δ, dissipation factor and dielectric loss factor.

3.2 Delta Tan Delta (△ tan δ)

The difference in loss tangent measured at two prescribed voltages, usually at 0·2 U_N intervals.

NOTE — Another term sometimes used for this property is power factor tip-up.

3.3 U_N

The rated rms phase-to-phase voltage by which the system is designated and to which certain operating characteristics of the system are related.

3.4 Form Wound

Coil or bars which are preformed to shape, insulated and substantially completed before insertion into the stator.

3.5 Non-Linear Resistance Grading

An extension of the corona shielding in the slot portion of the coil or bar embodying resistance characteristics which are non-linear with voltage. It has the purpose of reducing potential gradients along the surface of the coils where they protrude from the ends of the core.

3.6 Room Temperature

The reduced range standard ambient (18 to 28°C) which is permitted if the standard ambient temperature range up to 40°C given in Table 1 of IS 2260 : 1973 is considered too wide.

3.7 Random Sample Test

A test carried out on coils or bars which adequately represent the configuration of the finished item to be used in the machine, for the purpose of evaluating the basic design, type of materials, manufacturing procedures and processes used in the insulation system.

4 INTRODUCTION

4.1 The dielectric loss characteristics under consideration are those mainly relating to the main ground-wall insulation between the conductor structure (including internal corona shielding if such exists) and the external corona shielding. Only that part of the conductor insulation which is dielectrically in series with the ground-wall insulation enters into the measurement.

4.2 The dielectric loss angle (δ) of the insulation is declared in terms of the tangent of this angle (tan δ), which for the purpose of this Guide is defined as loss tangent. When the loss tangent is within the range 0 to approximately 100 × 10^{-3} it has practically the same value as the dielectric power factor (the cosine of the dielectric loss angle).

4.3 Loss tangent is usually measured over a range of voltages at 0·2 U_N intervals starting at 0·2 U_N and up to 1·0 U_N. The term delta tan delta (Δ tan δ refers to the differences in loss tangent measured between adjacent 0·2 U_N intervals (*see* Fig. 1). It is defined as delta loss tagent for the purpose of this Guide.

4.4 Loss tangent measurement using guard electrodes at voltages below the inception of discharges represents the magnitude of dielectric loss in the solid insulation. A significantly higher than normal loss measured on any coil or bar indicates some difference in the structure of the insulation, such as may arise from incorrect resin composition or inadequate cure. The effect of the degree of resin cure (crosslinking) on loss tangent can be seen when measurement is made in service on fully wound stators, in that the loss tangent reduces during the early life of the machine. This indicates that the degree of resin cure often increases for some time after the normal manufacturing process.

4.5 As the test voltage is raised, partial discharges within gaseous inclusions (voids) in the insulation structure or at the interface of winding stack and ground insulation cause an increase in loss tangent as the critical gradient on each void is exceeded. As a result conductive non-linear losses in the insulation structure may be present and also cause an increase in loss tangent with voltage.

4.6 Maximum values of loss tangent at 0·2 U_N (loss tangent 0·2) and loss tangent difference per 0·2 U_N voltage interval (Δ tan δ) are usually specfied in the relevant product standards.

NOTE — Loss tangent at 0·2 U_n (loss tangent 0·2)' the increment of (tan delta 0·6 U_n — tan delta 0·2 U_n) and maximum value of loss tangent difference per 0·2 U_n voltage interval (delta tan delta) are usually specified.

4.7 The loss tangent measurments which are covered in this Guide relate to the mean, or global, loss characteristics of the insulation as a whole. They give no indication of the distribution of loss within the specimen; therefore, the presence of localized areas of high loss in an otherwise low loss insulation is not detected.

5 LOSS TANGENT

5.1 Measurement of Loss Tangent (tan δ)

5.1.1 The loss tangent is measured on the coil or bar at sinusoidal voltage and at room temperature at voltage intervals of 0·2 U_N over the range 0·2 U_N to 1·0 U_N.

5.1.2 For coils, each coil side is to be measured separately and all results are recorded. The following information is obtained:

a) Loss tangent at low voltage (0·2 U_N);

b) Increment tan delta 0·6 U_N — tan delta 0·2 U_N;

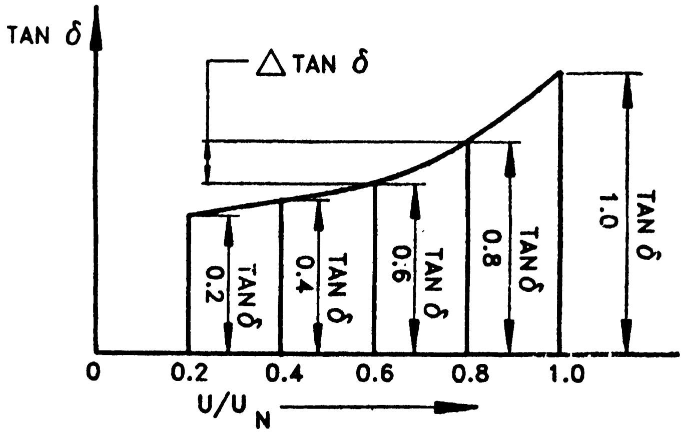

Fig. 1 Curve of Tan δ Against the Ratio U/U_N (Example of A Series of Measurements)

c) Delta tan delta for each voltage interval; and

d) Shape of voltage *versus* loss tangent curve (*see* Fig. 1).

5.1.3 If an automatic measuring system is used, the voltage is increased continuously. With this method of test it may be more convenient to express delta tan delta over smaller voltage intervals than 0·2 U_N depending upon the automatic measuring and evaluating system.

5.2 Method of Measurement

5.2.1 *Measuring Equipment*

5.2.1.1 Measurement is carried out by means of a Schering bridge or an equivalent type (Fig. 2 and Fig. 3) show connections of two typical bridges often used for normal measurement-Schering bridge and transformer-ratio arm bridge, ampere turn bridge/comparator bridge respectively in which tan delta is equal to $\omega\ C_1R_1$, for ungrounded specimen (*see* Note). A guard ring arrangement is usually required A variable amplitude alternating voltage supply is used, having sufficient rating to provide the test voltage across the capacitance of the specimen and complying with the requirements of IS 2071 (Part 2) : 1976.

NOTE — For a grounded specimen, two measurements with and without the specimen are needed to eliminate the effect of the components parallel to the specimen.

5.2.1.2 The bridge shall give values of loss tangent accurate to ± 1 × 10^{-5}. Checks on bridge and power supply shall be made to ensure that this accuracy is achieved whatever the appropriate bridge actually used.

5.2.2 *Preparation of the Test Coil or Bar*

5.2.2.1 When a permanent conducting coating is applied to the slot portion of the coil or bar for, purpose of corona shielding the this coating is used as the measuring electrode. The effect of coating resistance on the loss tangent measurement is avoided by applying, for example, a spiral wrapping of metal foil or wire over the full length (or slightly less than the full length) of the conducting coating.

5.2.2.2 When no such coating is used, a temporary electrode of conducting material shall be applied and uniformity of coating shall be checked at 20-40 different points depending upon the length of specimen ensuring that it does not differ by ± 10 percent of the average value.

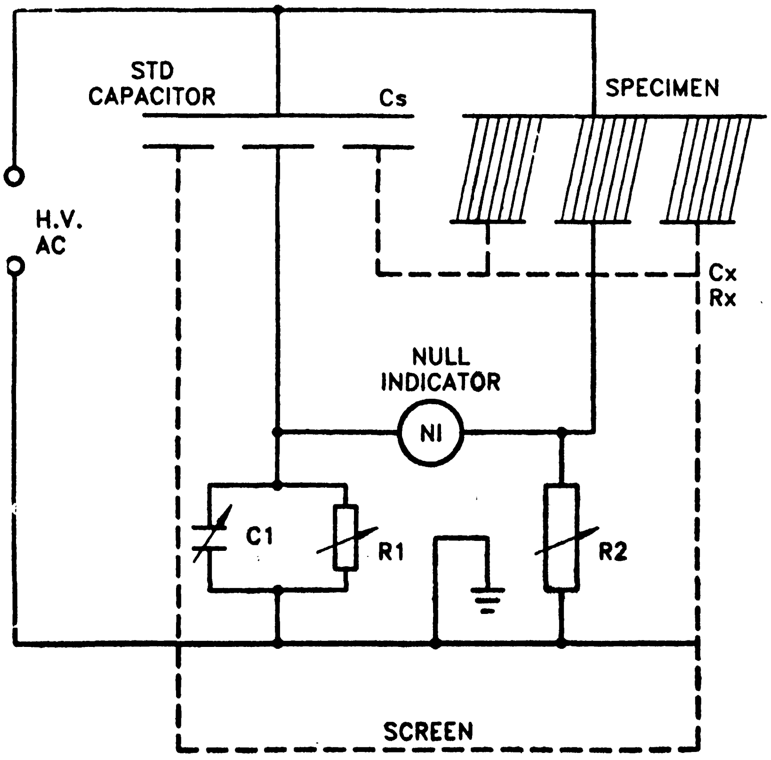

FIG. 2 H. V. SCHERING BRIDGE — BASIC CIRCUIT

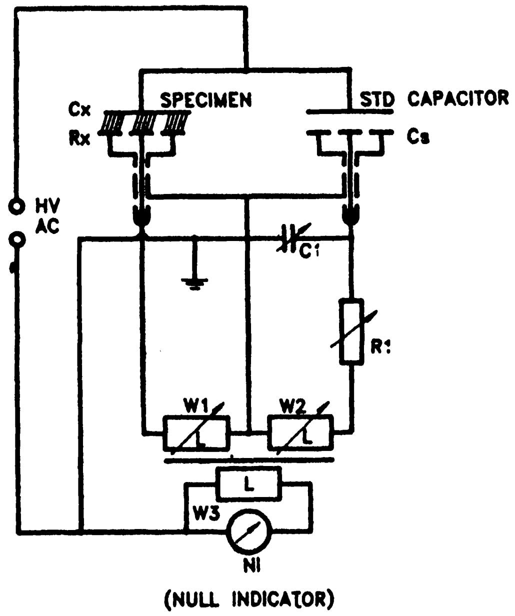

FIG. 3 AMPERE TURN BRIDGE ALSO CALLED AS COMPARATOR BRIDGE OF TRANSFORMER — RATIO ARM BRIDGE — BASIC CIRCUIT

5.2.2.3 Conducting guard rings, preferably of metal foil, should be applied so as to make intimate conduct around the coil or bar surface just outside the measuring electrode. The length of guard rings should be not less than 10 mm; the distance between the measuring electrode and each guard ring should be as small as practicable and not greater than 4 mm. The electrode arrangement is shown in Fig. 4.

5.2.2.4 Further practical details are given in Annex B.

5.2.3 *Test Procedure*

5.2.3.1 The coil or bar to be tested should be suitably insulated from earth. All the conductors should be connected to the high voltage side of the supply and the electrode and guard ring connected to the bridge circuit. Figures 2, 3 and 4 show the circuit and connection arrangements.

5.2.3.2 For explicit details of the procedure for checking the test circuit for stray effects, making appropriate corrections and carrying out the test, reference should be made to the instructions in bridge manual.

5.2.3.3 For good reproducibility of test results, each complete test sequence should be performed in approximately the same length of time. In the case of automatic measurement, the time for recording the whole curve should be not less than 15 s. For either method of measurement, pre-electrification, for example 15 s at 1·0 U_N has been found necessary in order to stabilize the results.

Readings shall be recorded in units per thousand to facilitate interpretation of results. Room temperature reading shall be recorded as tan delta varies with temperature.

NOTE — In the event of breakdown of the specimen during the measurements, safety for the operator from electric shock hazards and protection to the bridge must be ensured.

5.3 Evaluation

5.3.1 In order to judge the uniformity of manufacture, the initial value of tan δ at 0·2 U_N, the value of tan δ for the voltage interval 0·6 U_N to 0·2 U_N and the maximum value of Δ tan δ per 0·2 U_N voltage interval may be plotted on a chart with a linear scale of these characteristics against the scale of the gaussian cumulative distribution function. From this plot the characteristic value for 95 percent or 99·55 percent can be seen and may be limited.

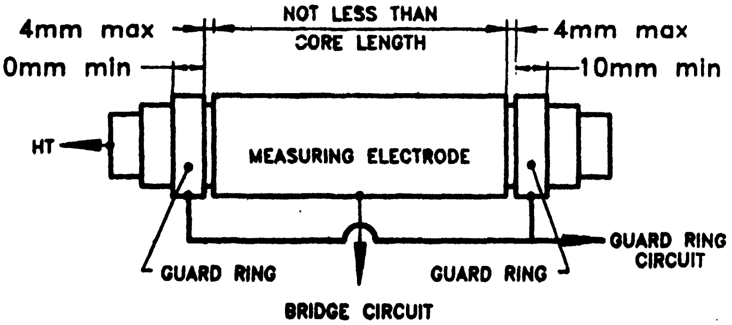

FIG. 4 ELECTRODE ARRANGEMENT

ANNEX A

(*Clause* 1.3)

POST IMPREGNATED MACHINES

A-1 In the case of machines whose windings are cured — in the stator, tests on the separate coils or bars are not possible because the dielectric loss characteristics of the slot insulation are not achieved until after the winding is inserted in the stator and the curing operation carried out. Tests can be carried out on the complete winding, but comparison of such results with those of tests on individual coils should take account of the fact that results from the complete winding can be considerably influenced by the non-linear resistance grading and the length of the slot portion.

A-2 With this type of machine a random sample test may be agreed whereby two identical coils (or four bars) are manufactured as for the production machine, at the same time and under the same conditions as the production winding and accommodated in slot models.

These samples are tested in accordance with this standard.

A-3 Results of tests carried out on these samples with guard electrodes and without guard electrodes but with non-linear resistance grading can be used to judge the influence of the corona suppression system, but the evaluation is not covered in this standard.

ANNEX B

(*Clause* 5.2.2.4)

MEASURING ELECTRODE AND GUARD RINGS

B-1 When metal foil is used as the measuring electrode, any voids under this foil will result in a substantial increase in measured value of loss tangent particularly at the higher voltages. Every effort should be made to reduce the air space under the foil.

B-2 Contact resistance with the measuring electrode and the resistance of the measuring electrode itself, unless reduced by means of a low resistance contact screen, can affect the results by showing a higher than true value at low voltage followed by reducing values (negative curve) over the first voltage intervals.

B-3 Normally there should be no electrical contact between the measuring electrode and guard rings and in the event of dispute, this is the standard arrangement. However, it is often found that guard rings can be applied on the non-linear resistance grading with no significant effect on loss tangent values, this method may be useful in routine production testing.

B-4 When it is required to determine the true loss tangent values of coils or bars which have the non-linear resistance grading applied before the resin is cured, it is necessary to introduce small gaps at both ends of the measuring electrode during manufacture. These gaps should be covered with a conducting coating after the test.

B-5 The coil or bar specimen to be tested shall be mounted according to the manner in which the electrodes are connected to the test voltage and the bridge (that is on ungrounded or grounded specimen mode). For the purpose of high voltage connection to specimen all the conductors of the coil or bar must be bunched together and both ends of the specimen connected to the high-voltage side. Care shall be taken to avoid sharp points in these connections and if they are unavoidable, the resulting electric stresses to be relieved by suitable sheet metal caps with rounded edges securely placed over these sharp points and electrically connected to the copper conductor of the specimen.

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